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# Conducting Polymers Application

Kareema Majeed Ziadan

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## 1. Introduction

Organic polymers are normally insulators, it can be presumed that conducting polymers must have an unusual structure. Polymers with conjugated  $\pi$ -electron (i. e. system have C=C conjugated bonds) backbones display unusual electronic properties such as low energy optical transition, low ionization potentials, and high electron affinities. The result is a class of polymers that can be oxidized or reduced more easily and more reversibly than conventional polymers. The effect of this oxidation or reduction on polymer is called doping, i. e. convert an insulating polymer to conducting one) Kroschwitz, 1988).

Conducting polymers (CPs) such as polypyrrole, polythiophene and polyanilines are complex dynamic structures that captivate the imagination of those involved in intelligent materials research. (Spinks, et al., 2000; Riley, & Wallace, 1991). The application of electrical stimuli can result in drastic changes in the chemical, electrical and mechanical properties of CPs. These complex properties can be controlled only if we understand, first, the nature of the processes that regulate them during the synthesis of the conducting polymers, and second, the extent to which these properties are changed by the application of an electrical stimulus. polyaniline and its derivative is one of important conducting polymer, it has many application such as organic light emitting diodes (OLEDs) (Burn et al, field-effect transistors (OFETs) (Nam et al 2011), corrosion (Solange, (2007) and solar cells (Alet, 2006. & McEvoy et al, 1994; Williams, 2005) In this chapter focusing on mechanism of conduction and mechanism of charge transport of organic conducting polymer. Also on application solar cell. chemical sensor and corrosion.

## 2. The mechanism of conduction

The polymer in their pure (undoped) state are describe as electronic insulators. When these polymer are doped the conductivity change from insulators to metals. The conductivity,  $\sigma$ , is proportional to carrier concentration,  $n$ , and the carrier mobility,  $\mu$ , i. e.

$$\sigma = e n \mu \quad (1)$$

For intrinsic conductivity,  $n$  decreases exponentially with increasing band gap, since the conjugated polymers have relatively large band gap, consequently,  $n$  is very low in normal temperature, so that a low value of  $n$  leads to a low value of conductivity of undoped polymers even-though the polymers have high carrier mobility Kroschwitz J. I, 1988

In doped polymers, the doping of conjugated polymers generates high conductivities by increasing the carrier concentration  $n$ . This accomplished by oxidation or reduction with electron acceptors or donors respectively. The polymer is oxidized by the acceptors (removal of electron), thereby producing a radical cation (hole) on the chain.

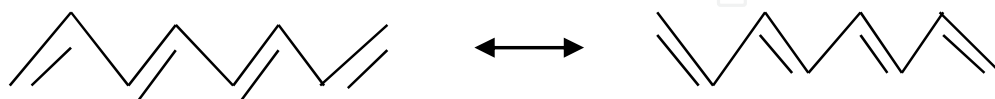
The radical cation with lattice distortion around the charge is called polaron with positive charged hole site. This hole site moves through the polymer and contributes to the conductivity. This polymer is called p-type polymer. For donor doped polymer (n-type) that is obtained by reduction is adding electron to the chain. This process produces polaron with negative charge. The Hall effect measurement in polymer shows positively charged carriers for acceptor doped polymer (p-type) and negatively charged carrier for donor-doped polymer (n-type). The thermo power and junction measurement show the same result as that determined by Hall-effect (Krichelore, 1992).

The doping concentration in polymer is high compared with that in organic semiconductors (in parts per – million). In some case the doping reaches 50% of the final weight of conducting polymer. This can be determined by chemical or spectroscopic analysis or simply by weight up take. The conducting polymer doped can be return to insulating state by neutralization back to the uncharged stat. This return to neutrality is referred as compensation. Exposure of ox datively doped polymers to electron donors or conversely, of reductively doped polymer to electron acceptors effects compensation. This ability to cycle between charged and neutral states forms the base for the application of conducting polymer in rechargeable batteries (Kareema 1997).

The doping process produce number of carriers in polymer, but these carriers must be mobile in order to contribute to conductivity, eq. (1). The carriers transport in doped conjugated polymer are analogies to doped semiconductor. In both cases doping introduces new electronic states within the band gap of material. The difference is that in conductive polymer, the total oscillator strength dose not increased upon doping, and generated polaron density of state is created by shifted the band density of state to band gap. At high doping concentrations these states interact strongly with each other, and as a result, the overlap of their electronic wave functions yield a band of electronic state within the band gap instead of discrete levels. The mechanism of carrier transport in conducting polymer is probably more likely to that in amorphous semiconductors (hoppingtransport) than crystalline semiconductors (band transport). A conclusion may be drawn that the doping creates an active sites (polarons) which enable the carriers (electronic & holes) to move from one site to another. By hopping mechanism through these sites.

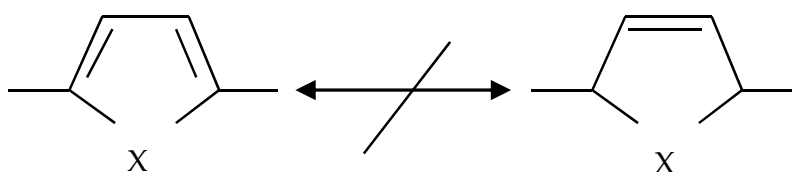
### 3. The mechanism of charge transport

The doping of conducting polymer induces charge transfer along the chains which leads to local relaxation. The equilibrium geometry in ionized states is different from that in ground state, and that the electronic structure is affected by the localized electron states in the gap which modify the  $\pi$  system. In order to understand the mechanism of conduction, we must have information about ground-state geometries and doped state. Polyacetylene has degenerate ground state (two geometric structures having the same total energy). The defect divides the chain of PA into two parts with the same energy. The movement of defect can be described by soliton scheme (1).



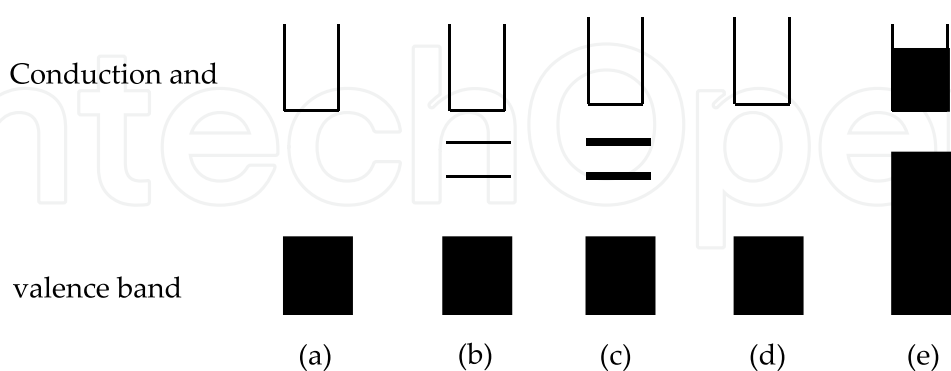
**Scheme 1.** Polyacetylene (degenerate ground stat)

Polythiophene, polypyrrole and heterocycle polymer processes a nondegenerate ground stats Kroschwitz J. I, 1988 scheme (2).



**Scheme 2.** Heterocyclic polymer  $x=S, O, NH$  (nondegenerate ground stats).

It has suggested that the stable defect state formed upon doping are polarons and bipolarons and optical data seem to support the evidence of the fommation of polarons (Single charge parameter state) and bipolarons. (Kareema 1997)



**Figure 1.** Schematic variation of band gap as a function of doping concentration \ (a) undoped (b) very small doping (polaron) (c) small doping (bipolaron) (d) high doping bipolaronic band (e) 100% doping (theoretically speaking).

Fig. (1-a) shows the neutral undoped heterocyclic polymer of band gap tabulated in table (1-1). Fig. (1-b) shows the doping levels of order (0. 1-1%) %. The appearance of an ESR signal

and of optical bands in the gap is consistent with formation of polarons. Fig. (1-c) indicates the increasing of the doping give rise a few percent (1-5%), leading to drop in spin concentration and the presence, in the optical data, two peaks located respectively below the conduction band and above the valence band indicated that the polarons bind in pairs to form diamagnetic bipolaron state. Fig. (1-d) expresses when the doping levels reach (25 – 50) mol. % the bipolarons states overlap and form the bands in the gap. Fig. (1-e) shows when doping reach to 100% (theoretically speaking) the bipolaronic band may merge with conduction band and valence bands respectively leaving a reduced gap. This is consistent with optical data indicating that the band gap disappear (Skotheim, 1986).

#### 4. Polymer solar cell

Polymer solar cells have attracted broad research interest because of their advantageous solution processing capability and formation of low-cost, flexible, and large area electronic devices. (Williams, 2005); Vignesh et al, 2006, Schiff, 2002). However, the efficiency of polymer solar cells is still low compared to that of inorganic solar cells. Therefore, it is a challenge to find a polymer that has all the required properties for high efficiency devices, such as strong and broad absorption, high carrier mobility, and appropriate energy levels. One possible solution to avoid the strict material requirements is to stack two or more devices with different spectral responses, which enables more efficient utilization of solar energy.

A typical example of the usability of organic semiconductors is the dye-sensitised solar cell which owes its first demonstration Gratzel and his co-workers (McEvoy et al., (1994); Michael, 2003).

Organic/inorganic hetero structure solar cells have also been studied recently and power conversion efficiency in the region of 2. 5% has been achieved by (Hussein, 2010). Solar cells based on conducting polymer/amorphous silicon (a-Si:H) structures have also been reported which demonstrate solar conversion efficiency in the range of 2% (Williams et al., 2005; Alet 2006). Blend heterojunctions consisting of a bulk mixture of poly (3-hexylthiophene) (P3HT) as donor and 6, 6-phenyl C61-butyric acid methyl ester (PCBM) as acceptor are very promising structures Brabec, C. J. (2004). Studies on blend nanoscale morphology Hoppe H. et al (2006) and stability of organic solar cells (Bettignies et al, 2006) are currently subjects of intense research.

In recent years, the development of thin film plastic solar cells, using polymer-fullerene (Gao et al., 1995); Shaheen et al., 2001) or polymer-polymer (Granström et al, 1998) bulk heterojunctions as an absorber (and transport layer at the same time), has made significant progress. Efficiencies between 1% and 2. 5% for laboratory cells under AM1. 5 illumination conditions have been reported (Gao et al., 1995;. Dyakonov. et al 2001). The typical structure of these devices consists of a composite of two materials with donor and acceptor properties, respectively, sandwiched between two electrodes. One advantage of this type of devices is their ease of processability. The active layer is solution processed by using spin-coating technique. Kareema et al, 2010). study photovoltaic properties of Polyaniline/Si solar cell in the dark and under illumination investigated hybrid and was found to deliver short circuit

current density  $J_{sc} = 45 \mu\text{A}/\text{cm}^2$ , open circuit voltage  $V_{oc} = 400\text{mV}$ , and solar cell efficiency  $\eta = 0.3\%$  under AM 1.5 simulated solar light with the intensity of  $100\text{mW}/\text{cm}^2$ .

In this paragraph investigated some of the photovoltaic properties of organic polymer poly (o-toluidine) (POT) doped with para-toluene sulphonic acid (PTSA) deposited onto n-type silicon substrates (Kareema, 2012) (this study part of thesis done under my supervisor by Hussein, 2010).

Poly (o-toluidine) (POT) doped with para-toluene sulphonic acid (PTSA) were prepared following chemical methods described in the literature (Kulkarni, & Mulik, 2005). Powder of the doped polymer was dissolved in formic acid ( $\text{HCOOH}$ ) in the concentration of  $10 \text{ mg. ml}^{-1}$ . Single layer heterojunction solar cells were then prepared by spin casting solutions of POT-PTSA onto the silicon substrates using spin speeds in the range 1000-5000 rpm and spinning time of 60 sec. Thin films were then placed on a hotplate with temperature of  $90^\circ\text{C}$  for a period of 15 min for drying. Aluminum (Al) contact of about 90 nm in thickness was thermally evaporated onto the back (the unpolished side) of the Si substrate. This was carried out under vacuum of  $10^{-5}$  -  $10^{-6}$  mbar and evaporation rate of  $5 \text{ nm. sec}^{-1}$ . Similar procedure was followed for the deposition of gold (Au) contacts onto the polymer film, with Au film thickness of about 20 nm evaporated through a suitable mask which provides device area of about  $3 \times 10^{-6} \text{ m}^2$ . For DC electrical measurements of the solar cell devices a Keithley electrometer (Model 6517A) was used to measure current density (J) as a function of applied voltage in range  $\pm 1\text{V}$  and in steps of 0.05V.

The photovoltaic properties of the solar cells were measured under illumination using a Bentham 605 solar simulator fitted with a xenon lamp. The photocurrent was measured for devices of different polymer film thickness and under four different light illuminating intensities between 10-100  $\text{mW}/\text{cm}^2$ .

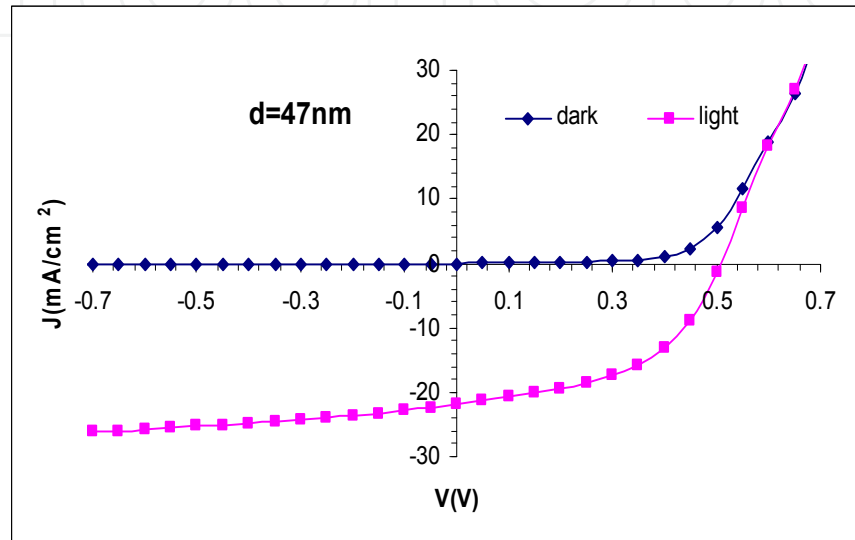
Figure (2) shows the J (V) characteristics of the fabricated POT-PTSA/n-Si solar cell structures, both in dark and under illumination. The polymer film thickness for this particular result is 35nm as determined by spectroscopic ellipsometry measurements and the illumination intensity is of  $100 \text{ mW}/\text{cm}^2$ . Both J (V) curves clearly possess good diode characteristics which clearly demonstrates the occurrence of a rectifying junction. This junction is expected to exist at the interface between the silicon substrate and the polymer film. This can be further justified by the fact that the silicon substrate used in this work is of n-type while the POT-PTSA films are considered as the hole transporting layer (Mangal et al., 2009). The POT-PTSA films are thin enough to allow the photon flux to reach the n-Si substrate and thus allowing the photocurrent current to saturate. Solar cell parameters, i. e.,  $V_{oc}$ ,  $J_{sc}$ ,  $V_p$ ,  $J_p$ ,  $P_{max}$ , and FF have been determined and are summarised in Table I. The solar conversion efficiency  $\eta$  is given by the formula:

$$\eta = (FF V_{oc} J_{sc} / P_{in}) \quad (2)$$

where  $P_{in}$  is the power of the incident light. A typical solar conversion efficiency value value of 2.55% for the studied devices is found to be in line with data found in the literature and are thought to be limited by uncontrolled interface states at the POT-PTSA/n-Si junction



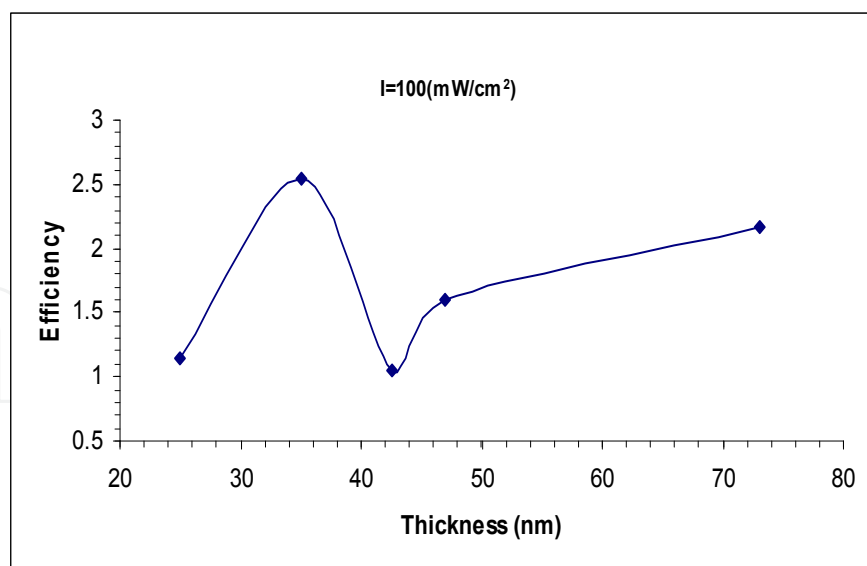
(Wang & Schiff, (2007). A closely related structure of the type aluminium / polyaniline / GaAs metal-insulator semiconductor solar cell was found to give efficiencies in the region of 5%. The value of 0.46 V for the short circuit voltage obtained in this work compares well with the value 0.51V obtained for Pani /n-Si solar cell devices (Wang & Schiff 2007). A low values of FF of about 0.43 is associated with a high series resistance and a low shunt resistance with typical values of  $37\Omega$  and  $465\Omega$ , respectively. High values for RS may originate from a poor absorber morphology limiting the electron hopping transport (Levitsky et al., 2004; Riedel et al., 2004).



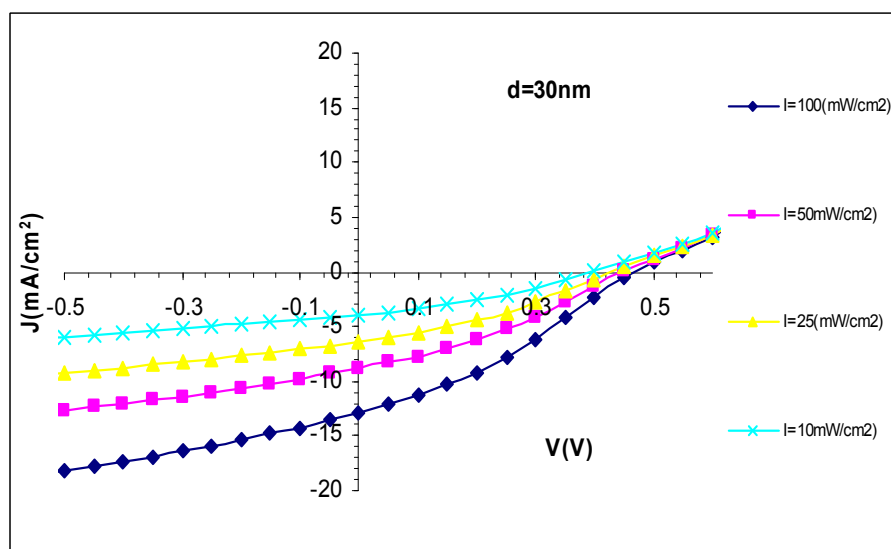
**Figure 2.** Current density as function of voltage for Au/POT-PTSA/n-Si/Al solar cell. The white light illumination intensity is  $100\text{mW/cm}^2$ .

Figure (3) shows the conversion efficiency as a function of film thickness of POT-PTSA spun films in the range 25-73nm. The efficiency is shown to increase sharply with increasing film thickness reaching a maximum value of 2.55% for film thickness of 35nm, and then decreases for slightly larger thickness (43 nm), before it starts to increase again, but more gradually, for higher thicknesses. The organic thin film of POT-PTSA is typically characterized with a lower charge carrier density and charge mobility compared to polyaniline which is subjected to a similar doping treatment (Kulkarni. & Viswais, 2004).

It is expected that for thin films of relatively small thickness (in this case 35nm), the surface texture is more suitable for light trapping compared to smaller or larger film (25nm and 43nm) (Izabela et al., 2008; Haug, et al., 2009). Furthermore, the gradual increase in light conversion efficiency may be associated with the increase in grain size leading to reduced grain boundary charge scattering. Figure (4) shows the current density as a function of applied voltage with different illuminating light intensities. The parameters of solar cells are tabulated in Table (I). The short circuit current and open circuit voltage are decreasing with decreasing illumination intensity, however, the solar conversion efficiency is found to increase with decreasing light intensity with a maximum efficiency of about 5% observed under  $100\text{ mWcm}^{-2}$ . Such effect has been associated with light dependent parallel resistance which affects the solar conversion efficiency of such devices.



**Figure 3.** Efficiency versus film thicknesses of (POT-PTSA) /n-Si solar cell at room temperature.



**Figure 4.** J (V) Characteristic of Al/n-Si/ (POT-PTSA) /Au solar cells measured at different light intensity with film thickness of 35nm.

Intensity	$V_{oc}$ (V)	$J_{sc}$ (mA /cm <sup>2</sup> )	$V_p$ (V)	$J_p$ (mA /cm <sup>2</sup> )	$P_{max}$ (mW /cm <sup>2</sup> )	FF	$\eta$	$R_s$ $\Omega$	$R_{sh}$ $\Omega$
100	0.46	13	0.34	7.5	2550	0.426	2.5	37	465
50	0.45	9	0.3	6	1800	0.444	3.6	44	719
25	0.44	6.5	0.24	4	960	0.335	3.84	46	917
10	0.38	4	0.22	2.2	484	0.318	4.84	55	1666

**Table 1.** Parameter calculated form J (V) characteristics of (POT-PTSA) at different light intensity (film thickness 30nm)



Photocurrent generation parameters of POT-PTSA/n-Si structures are expected to improve further by improving POT conductivity which can be achieved by increasing the ratio of the dopant (PTSA) concentration into POT solutions. Thin films of POT have been shown to have lower conductivity and charge mobility compared to Pani films due to the introduction of -CH<sub>3</sub> groups into the Pani chains in order to produce POT (Gordon et al., 2003). It was demonstrated that Pani Conductivity in the range  $10^{-5}$ - $10^1$  S/cm can be achieved by increasing its Xylene concentration. In the current work poly (o-toluidine) doped by para-toluene sulphonic acid was prepared following the procedure of Kulkarni and his coworkers (. Kulkarni et al., 2004). The conductivity of  $1.93 \times 10^{-3}$  S/cm was obtained for POT-PTSA samples in pellet form. Our preliminary study shows that solar cell properties based on hybrid structures incorporating POT-PTSA is quite promising. Therefore further work towards improving the electrical conduction properties of PTSA doped POT films is underway.

## 5. Chemical sensors

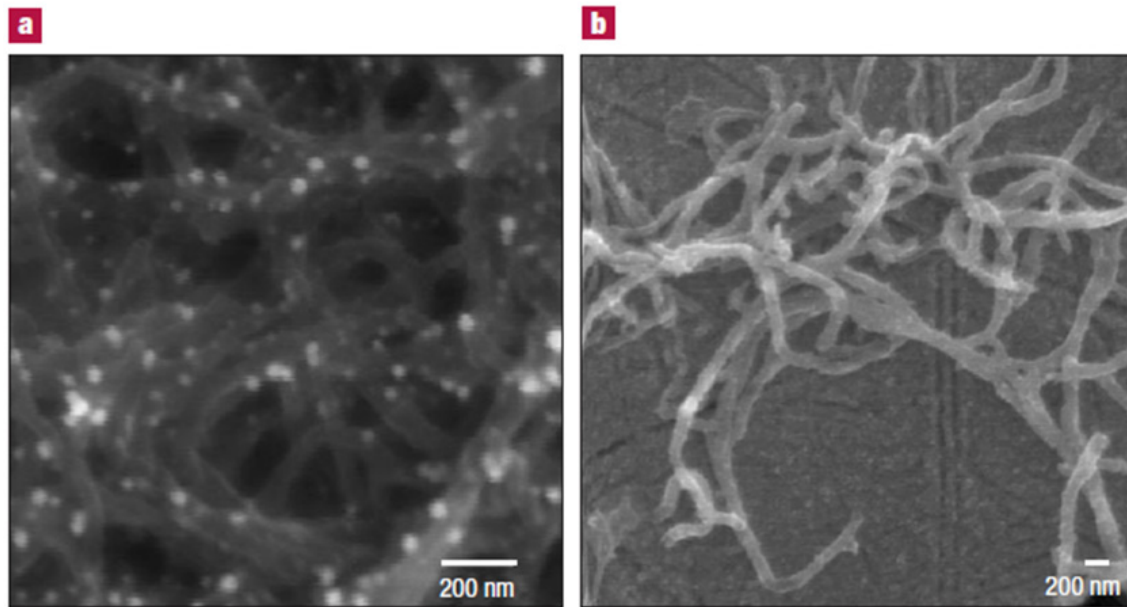
Conducting polymers, such as polypyrrole (PPy), polyaniline (Pani), polythiophene (PTh) and their derivatives, have been used as the active layers of gas sensors since early 1980. (McQuade et al, 2000].

There are two main types of applications for the Conducting organic polymers in electronics: first one is that a polymer can be used as a material for constructing different devices and as discriminating layers in electronic chemical sensors.

In both cases, interacting with surrounding gases is vital. It can possibly determine the performance of the devices that are depending on conducting polymers, while it is helpful and supportive in chemical sensors. Conductivity has been the main property of concern; the aim is of study and to identify the usability of the conducting polymers in the two kinds of electronic applications mentioned above.

Electronic Chemical Sensors for gases are thought of to be at the top of gaining the information related to the environment that we live in. The quality of the air that we breathe in our bodies is very important Issue and is a real concern of modern society.

The rich literature concerned about different applications of CPs could be classified within two groups: conducting polymers (CPs) in electronic (Angelopoulos, 2001), electromechanical (Gazotti, 2001), and optoelectronic (Otero, 2000) devices in the first group, and conducting polymers (CP's) in electronic chemical sensors that are based on the mechanisms of mechanical, electronic, or optical transduction (Bailey & Persaud, 2000). Sufficient operation of the first group depends on the chemical stability of the conducting polymers in the surrounding environment, where the applications of a sensor obtain benefit of the physical changes that occur to the CP as it is exposed to several chemical solvents. That property is due to the macroscopic and molecular structure of Conducting Polymers (CPs). They are quite open materials that allow gases to enter their inner structure (Fig5).



**Figure 5.** (a) polyaniline Open structure set by electropolymerization. The white dots are gold clusters created by immersion of the film (b), Filament growth onto compact and smooth 300-nm-thick layer of electropolymerized polyaniline

On the contrary, the resistance of usual “silicon solid-state electronics” to changes in the surrounding chemical environments is up to the exceptional passivating properties of the layers of the fine inorganic surface (Huber, 1985).

This statement will only discuss sensors that are based on the chemical modulation of the CPs electronic properties which result from interacting with gases. Recently, reviews have been about changes of other properties that are used as principles of transduction, e. g., mass (Milella, & Penza, M. SAW (1998) (36) or optical properties Leclerc, M (1999) (37), and in liquid applications (Michalska, & Lewenstam, 2000)

Carbon nanotube and single polyaniline nanofiber gas sensors were investigated (Da-Jing CHEN et al., 2012) in this study. Carbon nanotube gas sensor was constructed by means of dielectrophoresis. Single nanofiber was deposited as nanofiber sensor across two gold electrodes by means of near-field electrospinning without conventional lithography process. The nanofiber sensor showed a 2.7% reversible resistance change to 1 ppm NH<sub>3</sub> with a response time of 60 s. Carbon nanotube sensor showed good linearity in the concentration range above 20 ppm with response times between 100 and 200 s. The fibers with smaller diameter showed quicker response to NH<sub>3</sub> on the basis of gas diffusion mechanism. As such, CNT sensor and nanofiber-based sensors could be promising for gas sensing array and multi-chemical sensing applications.

Arenas (Arenas et al., 2012) studied conducting Polyaniline films (Pani) on Corning glass substrates, produced using either an in-situ doping process or a co-doping process, were prepared by the oxidative polymerization of aniline in N, N, dimethylformamide. Bicyclic aliphatic camphorsulfonic acid (CSA), aromatic toluenesulfonic acid (TSA) and carboxylic

trifluoroacetic acid. The codoped process reduces the roughness of the CSA-doped films by 50%, but the conductivity depends on the acid type used for this process (TSA or TFA). The optical gas sensor response of the films is related to both the morphology and the degree of protonation. In this study, Pani with a microfiber morphology obtained from TSA-doping is the most sensitive to ammonia gas sensing, and Pani with flower-like morphology is the least sensitive.

The performance at room temperature of nanostructured polyaniline (Pani) –titanium dioxide (TiO<sub>2</sub>) ammonia gas sensors was investigated by (. Pawar<sup>1</sup> et al., 2012) The PANi–TiO<sub>2</sub> thin-film sensors were fabricated with a spin-coating method on glass substrates. PANi–TiO<sub>2</sub> (0–50%) sensor films were characterized for their structural, morphological, optical, and various gas-sensing properties. The gas-sensing properties showed that the sensors exhibited selectivity to ammonia (NH<sub>3</sub>) at room temperature

Patil (Patil S. V et al., 2012) studied room temperature (300 K) liquefied petroleum gas (LPG) sensor based on n-polypyrrole/p-polyaniline (n-PPy/p-Pani) heterojunction has been fabricated using simple inexpensive electrodeposition method. The n-PPy/p-Pani heterojunction was fabricated by depositing polyaniline over predeposited polypyrrole thin film. The n-PPy/p-PANI heterojunction showed selectivity towards LPG as compared to N<sub>2</sub> and CO<sub>2</sub>. The room temperature maximum gas response of 33 % ( $\pm 3$  %) was achieved upon exposure of LPG at 1040 ppm

Conductive polyaniline (Pani) and single-walled carbon nanotube (SWNT) composite materials and its sensing property when NH<sub>3</sub> and CO gases co-existed investigated by (Hyang Hee Choi et al., 2012). To improve the gas sensor properties, we deposited PANI using a drop-casting method to wrap the Pani surrounding the SWNT. The Pani/SWNT composite material sensors showed a faster response to NH<sub>3</sub> gas than CO gas. The CO gas increased the composite conductance, while the NH<sub>3</sub> gas had the opposite effect.

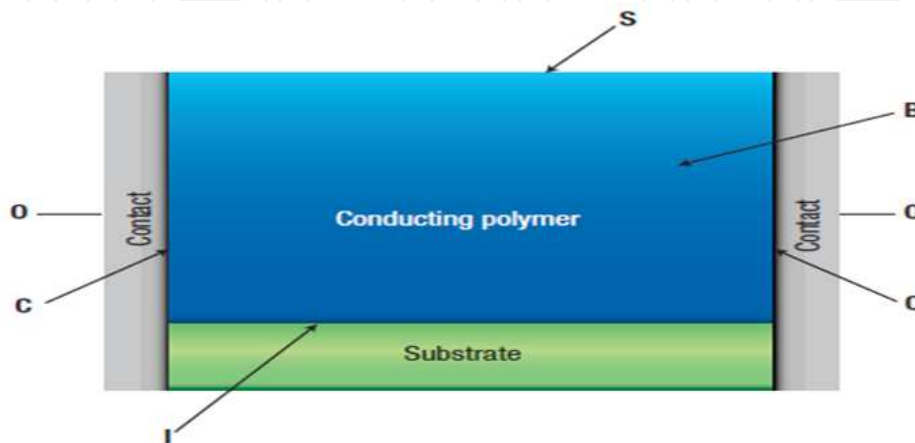
Conducting polymers (CP's) could be utilized as discriminating layer in a sensor or to be the transducer itself. Therefore, for instance, change in conductivity of a Conducting Polymer as it is exposed to a gas is the mechanism of sensing in a chemiresistor or field effect transistor characteristic.

### 5.1. Chemiresistors

The most widespread group of sensors is those that use Conducting Polymers. They are cheaply and quite easily made-up. In addition they utilize of the main property of Conducting Polymers (their conductivity). See figure. 6 shows a schematic diagram of a chemiresistor.

At its basic, a Chemiresistor is simply formed by two electrodes as contact points with the conducting polymer (CP) put onto an insulate substrate. When applying a constant current, the probable difference occurs on the electrodes represents the response output signal.

Although. The easiness of the sensing concept and its recognition does not come without a price. Since it is rarely to know what is occurring between the two electrodes. There will be a number of spots whereby the chemical change of a signal might initiate (Fig7) (Janata, 2002). For the measurements that use a constant current the capacitors used with equivalent resistors could be ignored. However, these capacitors have very significant role if an alternating current is used to excite those chemiresistors as well as if transient signals are involved.



**Figure 6.** “Chemiresistor; B: bulk of the CP, S: surface, I: interface with the insulating substrate. C: interface with the contacts”.

Polyaniline by chemical method then used as ammonium gas sensor (Kareema et al., 2010; Rawanq, 2009)

The conducting polymer CP can be acting as electrons donor or electrons acceptor when it is interacting with gaseous forms. The Hole Conductivity of a conducting polymer increases when it acts as an electron donator to the gas, on the other hand, the conductivity of the same conducting polymer decreases when it accepts electronics from the gas. Beside the changes of the carriers' number, changes could occur to their mass mobility. This is normally because of the adaption changes of the CP backbone (Zheng, 1997). Drawback of initiating the response in the mass of a Conducting Polymer is relatively long time (parts of second till a few minutes), usually coupled with a delay. Those consequences happen because of the slow diffusion of the gas into the Conducting Polymer. Due to the secondary doping results of modulation of the carrier number and the mobility, their related role in the total conductivity change differs. Change in the conductivity on the CP/electrode contacts could attribute to modulation of the Schottky barrier height. The contact barrier value is defined by the difference into work functions of both the organic semi-conductor and the metal. At this contact, there is a space-charge area generated into the interface of the semi-conductor and the metal. This means that the effecting resistance depends on the applied bias voltage as the measurement is being carried out. It was calculated (Leising et al., 1998) that for a Conducting Polymer with about 3V energy gap and carrier concentration of  $n > 10^{17} \text{ cm}^{-3}$  on contact with a small work function metal (e. g., 2.7 eV to calcium) the “depletion

width" was <30 nm. The conductivity changes on the surface are much more complicated to be interpreted due to the complexity of the surface morphology.

Even though it is possible to describe the basic interaction with the analyte by one of adsorption isotherm forms, its outcome onto the surface layer conductivity is much more complicated compared with the case of semi-conducting oxide sensors (Barsan & Weimar, 2001). It is an acknowledged fact that the conductivity of matching samples of a Conducting Polymer differs from preparation to another. Such variability is referred to the sort preparation method and the film thickness (Stussi et al., 1997), which has a great effect on the surface morphology (Fig. 1b). Fine films (<300) of PANI electro-chemically developed are soft and compacted, in contrast the thick films have dendritic structure of the surface (Josowicz, & Janata, 2002). The interface amid the Conducting Polymer and the insulating substrate is an additional place that could add to the total conductivity. Substrates such as (quartz, glass, sapphire... etc) are normally oxides. It is acknowledged (Domansky, et al. 1993), that the conductivity of the surface for oxides changes with the hydration degree. Therefore, the well known interferant to a chemi- resistor run at room temperature is the water vapour. To avoid this problem, it is recommended to make the substrate surface hydrophobic when performing the deposition of the conducting polymer.

All Those things and their unexpected behavior do not allow the precise analysis of the chemiresistor results to be easy, and several supportive techniques are often required to achieve additional detailed characterization. Because of all of that, the following techniques have been in use; Spectroscopy for Impedance (Ogura et al., 2001; Musio, et al., 1995), methodical changes of the chemiresistor geometry, changes of the electrodes geometry (Ingleby et al., 1999) and their materials. However, the relationship between the analyte gas concentration and the measured bulk conductivity (the response of chemiresistor) is constantly experimental.

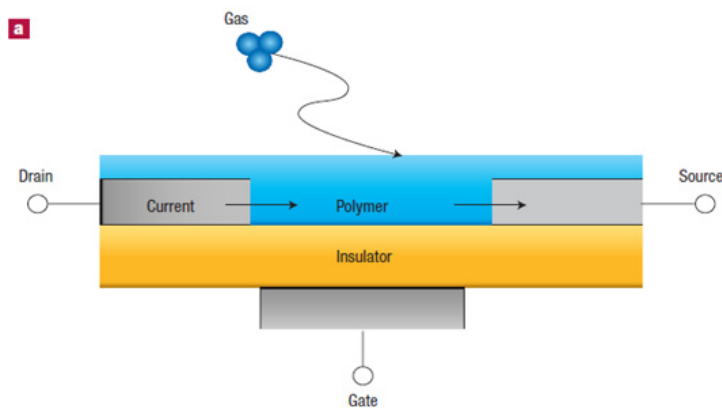
## 5.2. Field-Effect Transistor (FET) sensors

The interaction among the neutral gases and organic semi- conductors has been utilized as the principle of transduction in Field-Effect Transistor (FET) sensors from the late 1980s (Josowicz & Janata, 1986), while it has been almost uncared for within non-sensing applications.

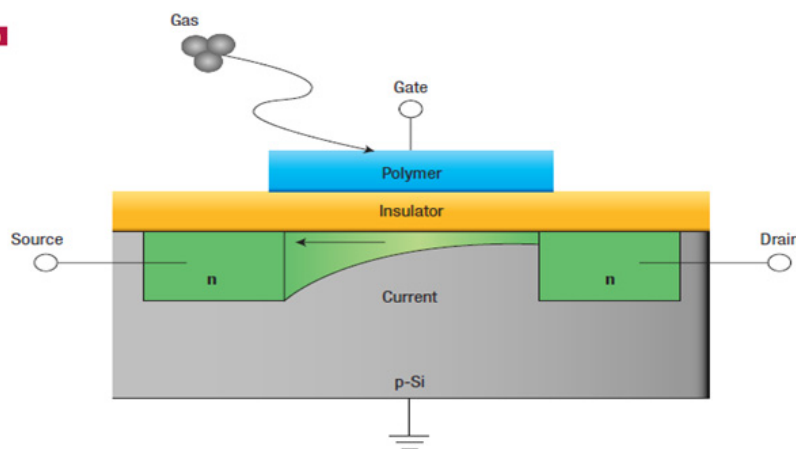
The category of sensors that are based on work function modulation contains three kinds of Micro Fabricated Devices which are; "Chemically sensitive Diodes, chemically sensitive capacitors, and chemically sensitive FET's (CHEMFETs) "

Several systems of CHEMFETs are found for both applications of liquid and gas species (Josowicz, & Janata, 1988). It is really key point to differentiate whether the current runs throughout the silicon or throughout the conducting polymer CP. In this case they could be divided in more detailed categories as follows; (a) thin film transistors (TFT) (Covington et al., 2001) as seen in figure 7 and (b) insulated gate Field-Effect Transistors (IGFET) (Janata, 1989) as shown in figure 8





**Figure 7.** Shows C P'S in field-effect transistors, thin film transistor

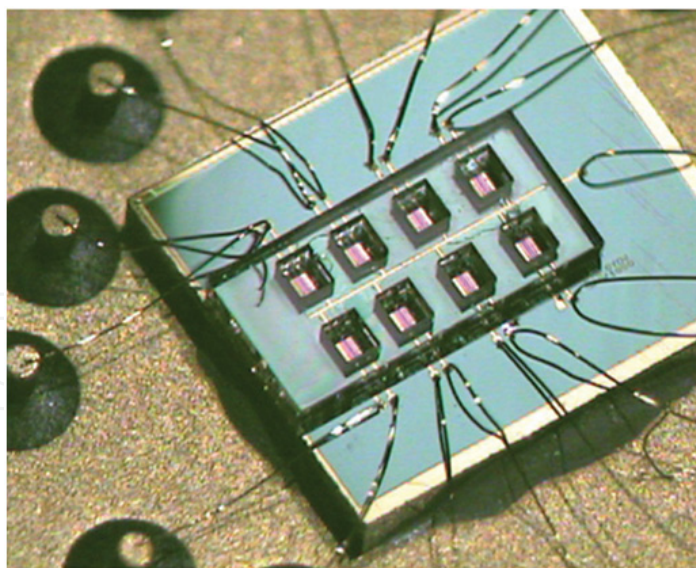


**Figure 8.** Shows CP's in field-effect transistors, insulated gate

For the TFT the current flows throughout a conducting polymer (CP) that its conductivity produced from the reaction with the analytes and/or by the electric fields. So, it can be said that the response signal depends on two things; the work function and the conductivity of the Conducting Polymer. Therefore, the analysis of the TFTs chemical response will be complex due to the same reasons for the chemiresistors, specifically, the division of different types of conductivity modulation, and of various forms of work function. The work function values can be affected by the interpreted energy states but the conductivity of the Conducting Polymer (CP) cannot be (Polk et al., 2002).

Conversely, in other usual silicon based transistors the situation will be very simple when the Conducting Polymer is employed only as a gate conductor. Then, the current will flow from side to side using the silicon channel, and the CP conductivity will not make any difference.

The Output response of these sensors relies just on the chemical modulation of a conducting polymer's work function. The possible outcome of the tuning of work function is the probability of building multi-sensing micro fabricated arrays. Look at figure (9) which shows a general platform for a similar array has been constructed.



**Figure 9.** A sensor array consisting of eight CHEMFETs, for more details look at (Polk, et al., 2002).

## 6. Corrosion

Conducting polymers of various forms will be electrodeposited onto oxidisable metals and electrochemical and environmental means will be used to access their applicability for corrosion protection.

Polyaniline (Pani) (Zhong et al., 2006; Wejood, 2005) and its derivatives (Bernard et al. 2006) are among the most frequently studied CPs used for corrosion protection. In addition, the use of PANI for corrosion protection of metals has been of wide interest since the works by (DeBerry 1988; Mengoli et al. 1981) reporting that electro active coatings of the Pani could provide adequate protection against corrosion of stainless steels and iron sheets, respectively. Ever since, numerous studies have been published in which various CPs in different configurations were evaluated for corrosion protection of different metals and alloys: mild steel (Pritee, et al., 2006; Wejood, 2005, Solange de Souza, 2007).

(Pritee et al. 2006), study electrochemically synthesized of polyaniline on mild steel from an aqueous salicylate medium. The extent of the corrosion protection offered by polyaniline coatings to mild steel was investigated in aqueous 3% NaCl solution, 0.01M Na<sub>2</sub>SO<sub>4</sub> solution and in aqueous solutions of NaCl+Na<sub>2</sub>SO<sub>4</sub> with different concentrations by potentiodynamic polarization technique and electrochemical impedance spectroscopy (EIS). The results of these studies reveal that the corrosion resistance of the polyaniline-coated mild steel is significantly higher and the corrosion rate is considerably lower than that of uncoated steel.

Polyaniline (Pani) nanofibers were successfully fully synthesized by a modified rapid mixing method (Sude Ma et al. 2012), that is, by the rapid mixing of solutions of aniline and ammonium peroxydisulfate in either hydrochloric acid or filtrates of oxidative polymerization of aniline. Composite coatings were fabricated with the dispersions of nanofibrous PANI and solutions of epoxy. Greatly enhanced corrosion protection



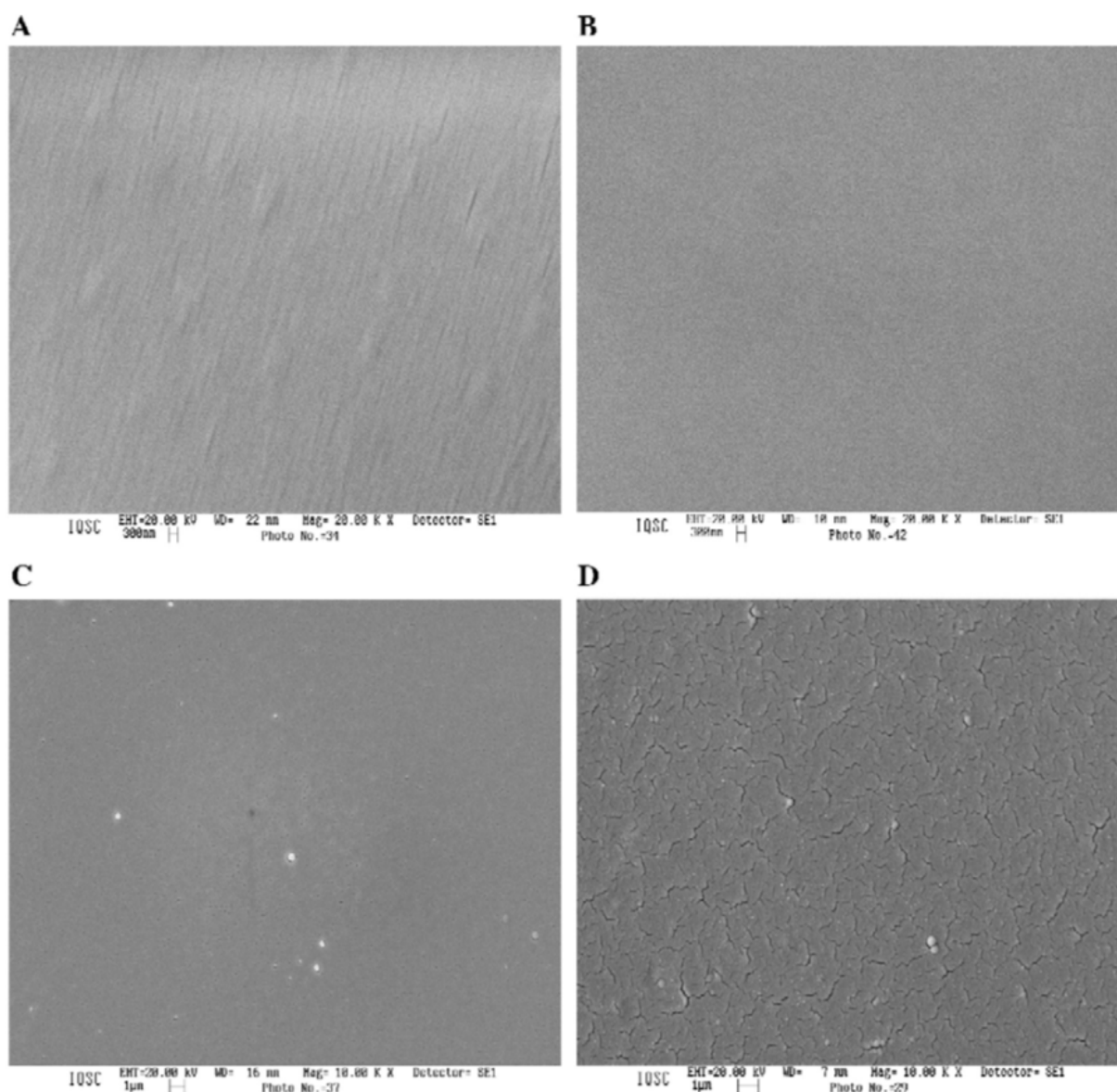
performances were demonstrated by the coatings loaded with a small quantity of nanofibrous Pani.

Kamaraj et al. (2012) have been syntheses polyaniline (Pani) and polypyrrole (Ppy) and studied the effect of electropolymerised Pani films on corrosion protection performance of epoxy coating on AA 2024 and AA 7075 aluminium alloys. Polyaniline was electropolymerised on both the alloys by galvanostatic method. A post treatment of cecrium was given to seal the pinholes of PANI film. Epoxy coating was applied over these films and their corrosion protection performance was found out by EIS studies in 3% NaCl and salt spray test. EIS studies have shown that the coating resistance ( $R_c$ ) of PANI with the epoxy coated aluminium alloys has remained above  $106 \Omega \text{ cm}^2$  whereas the alloys coated with epoxy alone have shown the  $R_c$  values less than  $104 \Omega \text{ cm}^2$ . Besides, the salt spray tests showed a better corrosion protection of PANI with epoxy coated aluminium alloys.

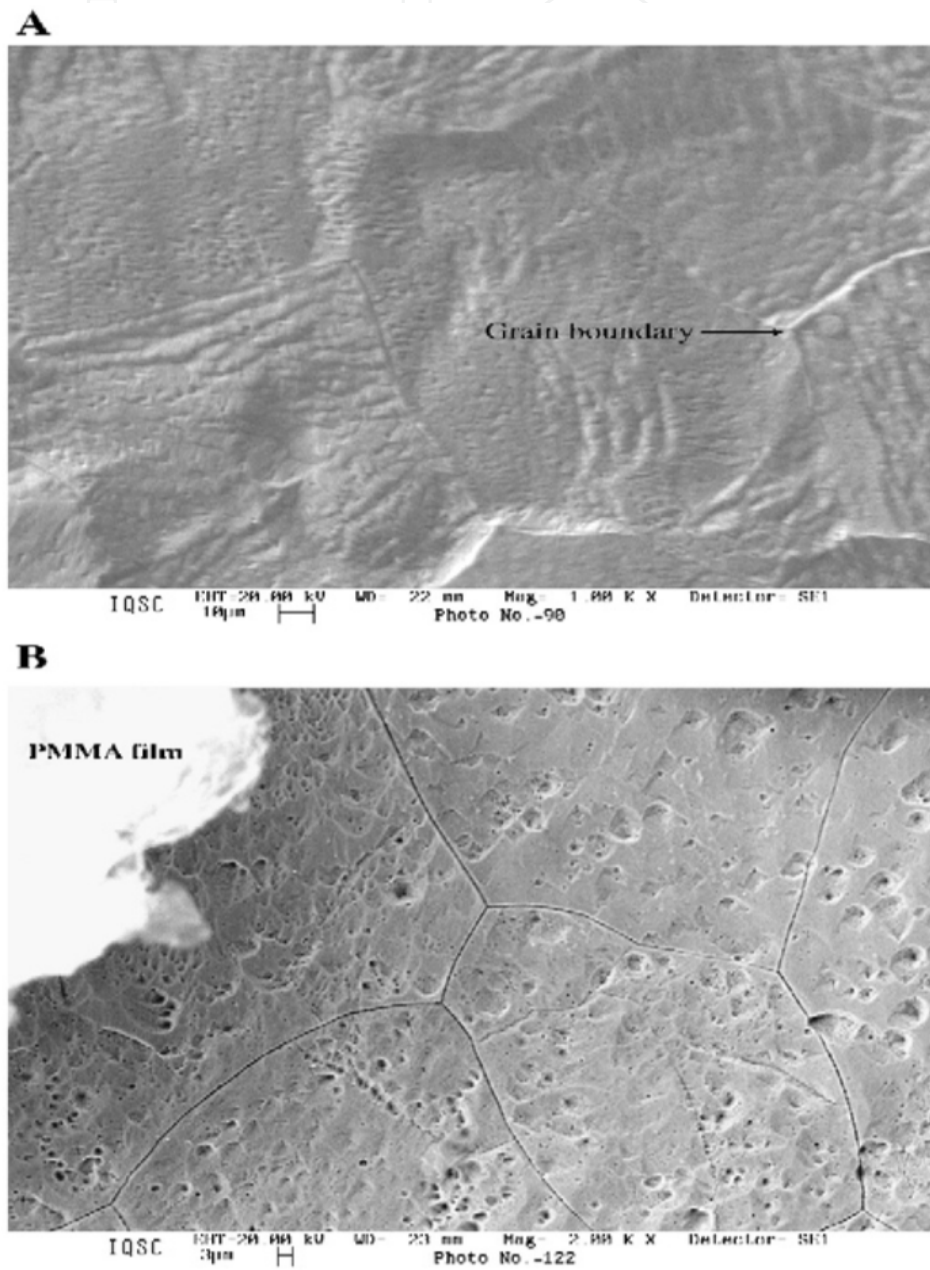
Good research investigates the possibility of improving the corrosion resistance of buried steel by coating it with polyaniline (Pani) layer, (A. H. El-Shazly & H. A. Al-Turaif, 2012). The formed Pani layer was examined for its corrosion resistance while coupled with stainless steel cathode and buried in sand containing different known amounts of moisture, salt (NaCl) and sulphuric acid ( $\text{H}_2\text{SO}_4$ ) using the potentiodynamic examination test. The results show that coating steel with Pani layer can improve its corrosion resistance against NaCl,  $\text{H}_2\text{SO}_4$  and water by factors up to 1.88, 1.89 and 1.54 respectively

Solange de Souza (2007) work vary good research, he studies the electrochemical behavior of a blend formed by camphor sulphonate-doped polyaniline and poly (methyl methacrylate) used for iron, copper and silver corrosion protection in acidic environments with or without chloride ions. The results obtained showed the good efficiency of these polymeric coatings against metal corrosion, proved by open circuit potential, linear voltammetry, electrochemical impedance spectroscopy, and scanning electron microscopy. It was observed that the protection depends on the formation of a passive film between the polymeric coating and the metallic substrate. SEM technique. Show at Fig. 10 (A) and (B), the micrographs reveal polymeric films with quite homogeneous morphologic appearance. As a consequence of the high miscibility of both acrylic polymers (PMMA) and the conducting [Pani (CSA)] amidst organic solvent, the presence of polymeric agglomerates is not observed in the films of Pani (CSA) -PMMA. After OCP and LV measurements, scanning electron microscopic micrograph of the Fe/Pani (CSA) -PMMA electrode reveals that surface is covered by homogeneous film [Fig. 10 (C)]. On the other hand, after OCP and LV measurements, visual observation of the Fe/PMMA electrode reveals a damaged film with many cracks [Fig. 10 (D)]. This damage may explain the lower OCP (around  $-0.56 \text{ V (SCE)}$ , value corresponding to iron dissolution) and the higher current density value of approximately  $2.0 \times 10^{-2} \text{ A cm}^{-2}$ . More information about the ability of this Pani (CSA) -PMMA blend to provide stabilization and enhancement of the iron passivity against pitting corrosion was obtained by peeling off the Pani (CSA) -PMMA layer and observing the metal substrate. After removing the organic film and the powder precipitated between this film and the iron surface, the formation of a second physical barrier was observed. Fig. 11. (A) shows an appearance of little iron dissolution, which is attributed to Pani (CSA) polymer

and to The coating based on polyaniline acrylic blend stabilized the potential of the metals Cu and Ag in a passive regime, maintaining a protective layer on the metal. The SEM micrographs of Pani (CSA) –PMMA-coated Cu and Ag electrodes Fig. 12 (A) and (B), respectively indicated that, after 85 days of immersion of these electrodes in acid solution, the morphology of Pani (CSA) –PMMA films did not show significant inference in comparison with the Fe/Pani (CSA) –PMMA electrode [Fig. 10 (C) ]. After removing the polymeric coatings, the forming of a second physical barrier between the copper and polyaniline film was observed [Fig. 12 (C) ]; whereas, for Ag/Pani (CSA) –PMMA electrode, there was no precipitate at the interface between polymeric coating and silver substrate [Fig. 12 (D) ]. second layer that avoided penetration of aggressive ions.

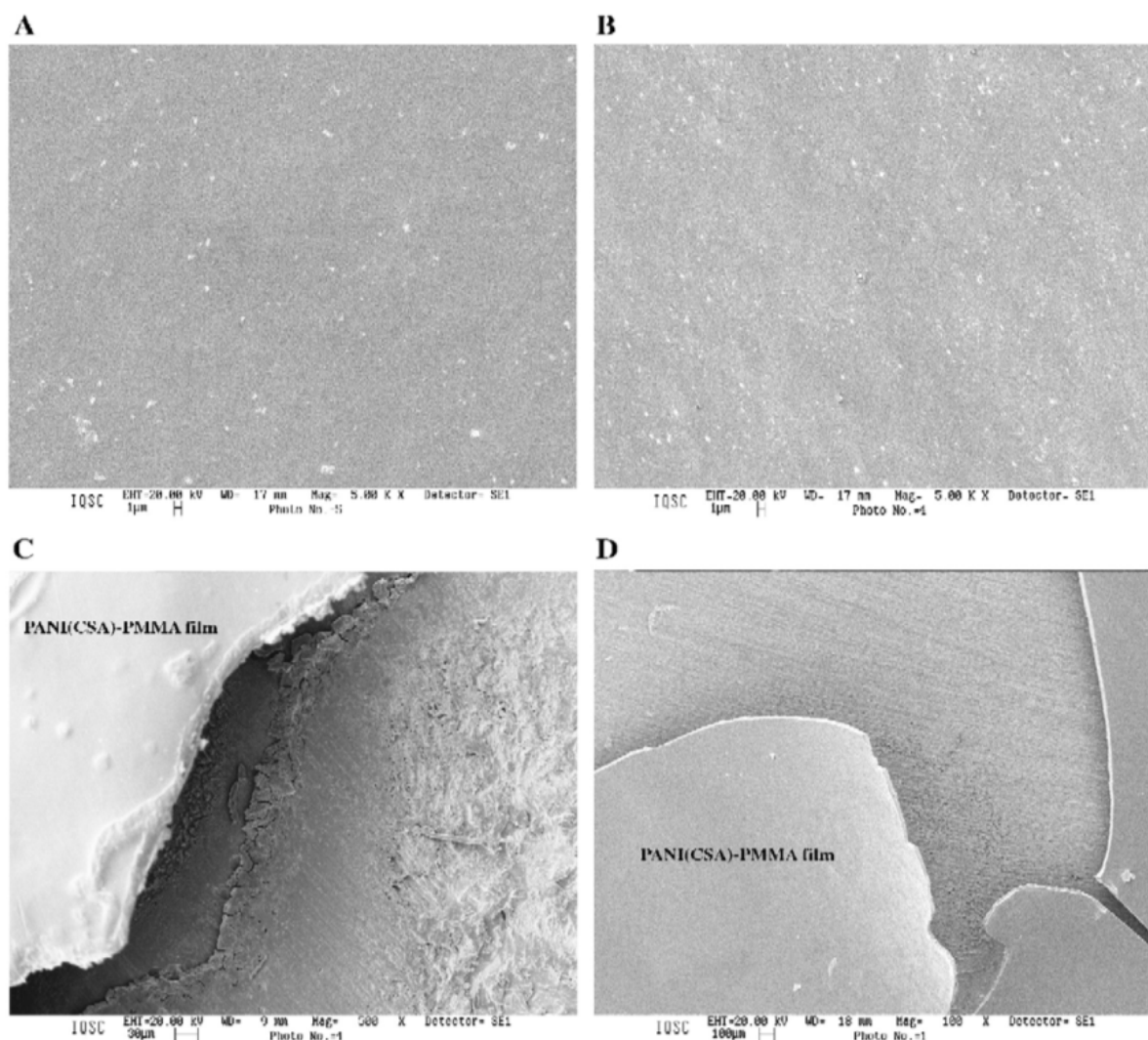


**Figure 10.** SEM micrographs of the (A) Pani (CSA) –PMMA film on Fe and (B) PMMA film on Fe, before OCP and LV measurements, and (C) Pani (CSA) –PMMA film on Fe and (D) PMMA film on (Solange de Souza 2007)



**Figure 11.** SEM micrographs of the (A) Fe/Pani (CSA)–PMMA interface, after removing of the polyaniline film and powder precipitated and (B) Fe/PMMA interface, after removing of the acrylic film, after OCP and LV measurements (Solange de Souza 2007)





**Figure 12.** SEM micrographs of the (A) PANI (CSA) –PMMA film on Cu, (B) Pani (CSA) –PMMA film on Ag, (C) Cu/Pani (CSA) –PMMA interface, after removing of the polyaniline film and (D) Ag/Pani (CSA) –PMMA interface, after removing of the polyaniline film, after OCP and LV measurements. (Solange de Souza 2007)

## 7. Conclusion

Conducting polymers have an immense advantage of being simple to synthesis, with their chemical structure tailored to alter their physical properties, such as their band gap. They exhibit an extensive range of electrical conductivity and can exhibit metallic to insulator property ( $10^5$ -  $10^{-9}$  S/cm). Further to their ease of synthesis and with lower cost, they are known to have low poisoning effects. So that they have many applications such as solar cells, sensors and corrosion. Solar cells devices incorporating thin films of poly (o-toluidine) doped in p-toluene sulfonic acid (PTSA) spin-coated onto n-Si substrates have been produced and their photovoltaic characteristics have been studied and discussed. Solar conversion efficiency of about 2.55% is Acknowledgments obtained for films with thickness of 35 nm. This efficiency is found to depend on film morphology as determined by the effect of film thickness and that lower incident light intensity is shown to cause an increase in these devices efficiency.

## Author details

Kareema Majeed Ziadani

University of Basrah, College of Science, Department of Physics, Basrah, Iraq

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